Overview of the Spaceborne imaging Radar-C / X-band Synthe tic Aperture Radar (SIR-C/X-SAR) Missions

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The Spaceborne imaging Radar-C/ X-band Synthetic Aperture Radar (SIR-C/X-SAR), the most advanced imaging radar system to have flown in Earth orbit, was carried in the cargo bay of the Space. Shuttle Endeavour in April and October, 1994. S1 R-C/X-SAR simultaneously recorded data at three wavelengths (1 ,-, C.-, and X-bands; 23.5, 5.8 and 3.1 cm, respectively). in addition, the full polarimetric scattering matrix was obtained at 1.- and C-band over a variety of' terrain and vegetation types. Scientists arc using multifrequency, polarimetric SIR-C/X-SAR data in studies of geology, hydrology, ecology, oceanography and radar remote sensing techniques. The October S1 R-CL -SAR flight also included acquisition of experimental repeat-pms interferometry data which have been used to generate digital elevation models and to detect surface motions in volcanic, tectonic and glacial terrains. Results from SIR-C/X-SAR clearly show the increased value of using multiparameter and interferometric capabil it ies to characterize earth's surface and vegetat ion cover and to ge.nc.rate geophysical products compared with optical sensors or single-channel radars alone.

Introduction

The Spaceborne Imaging Radar-C / X-band Synthetic Aperture Radar (SIR-C/X-SAR) is the most advanced imaging radar system to have flown in Earth mbit. Carried in the cargo bay of the Space Shuttle Endeavour in April and October, 1994, SIR-C/X-SAR simultaneously recorded SAR data at three wavelengths (1 ,-, C-, and X-bands; ?3.5, 5.8 and 3.] cm, respectively). In addition, the full polarimetric scattering matrix was obtained by the SIR-C instrument at I,- and C-band over a variety of terrane and vegetation types. The integrated system is steerable in look angle (electronically in the case of SIR-C, mechanically in the case of X-SAR) to obtain da(a in the angular range of 15°-600. imaging resolution varies from about 10 to 50 meters, depending on the geometry and data taking configuration. Over the two flights, a total of 143 hours (93 terabits) of SAR data were digitally recorded on tape for subsequent processing in the 11. S., Germany, and Italy (e. g. Evans et al., 1994; Stofan, et al., 1995; Jordan et al., 1995).

SIR-C/X-SAR is a cooperative experiment between the National Aeronautics and Space. Administration (NASA), the German space agency, Deutsche Agentur fuer Raumfahrta ngelegenheiten (DARA), and the Italian Space. Agency, Agenzia Spaziale Italiana (ASI). SIR-C was developed by NASA's Jet Propulsion Laboratory. X-SAR was developed by the Dornier and Alenia Spazio companies, with the Deutsche Forschungsan stalt fuer Luft und Raumfahrt (DLR), the major partner in science, operat ions, and data processing. 'The experiment provides an evolutionary step in NASA's Spaceborne imaging Radar (S11-?) program that began with the Seasat SAR in 1978, and continue.d with SIR-A in 1981 and SIR-B in 1984. It also represents a continuation of Germany's imaging radar program which started with the Microwave Remote Sensing Experiment (MRSE) flown aboard the Shuttle on the first SPACELAB mission in 1983 (e.g. Evans et al., 1993).

Data from the April and October SIR-C/X-SAR flights provide a synoptic view of changes on a short temporal scale and a baseline from which lol)gcl'-tcrm changes can be assessed in the future. High quality data were acquired over all planned targets, and in addition, the mission afforded unique opportunities to observe flooding in Illinois and Germany, three different views of tropical cyclone Odille, and a significant volcanic eruption of Kliuchevskoi volcano on the Kamchatka peninsula (Figure 1). SIR-C data were downlinked, processed, and released via Internet within 24 hours after launch. X-SAR data were processed in survey mode and displayed in real time (Evans et al., 1994, Stofan, et al., 199 S).

Summary of Results

The SIR-C/X-SAR Science Team consisting of 52 investigator teams from more than a doze.n countries arc using SIR-C/X-SAR data in studies of ecology, hydrology, geology, and oceanography. Other investigations arc focused on topics in SAR calibration and electromagnetic theory. Interferometric data from S1 R-OX- SAR are also being used for t orographic mapping, and surface change monitoring connected with natural hazards. In addition, SIR-C/X-SAR measurements of rain storms demonstrated for the first time, the. capabil ity of a multifrequency, multipolarization spaceborne radar s ystem to quant i fy precipitation rates and to classify rain type (Jameson et al., 1996). Since the flights in 1994, hundreds of additional investigators have accessed SIR-C/X-SAR data for studies as diverse as archeology, land-use, and resource management indicating that new findings and discoveries can be expected from this data set for many years to come.

Kasischke et al. (1996) provide a general overview of use of imaging radars for ecological applications. The primary applications of multi-parameter SAR data such as those obtained by S11<-UX-SAR to problems in ecology are: land-cover classification and forest growth estimates (e.g. Dobson et al., 1995; Ranson et al., 1995; Ranson and Sun, 1996; Saatchi et al., 1 996; and Rignot et al., 1996a), biomass estimation (e.g. Dobson et al., 1995; Harrell et al., 1 996), and mapping of wetland inundation (e.g. Hess et al., 1 995; Pope et al., 1996). SIR-C/X-SAR data have been used in several hydrology studies to improve our understanding of the role of water in the global climate and for management of water. Examples include snow wetness mapping (Shi and Dozier, 1 995), soil moisture estimation (Dubois et al., 1 995; Wang et al., 1 996), and flood monitoring and damage assessment (Izenberg et al., 1996). in each of these studies, multiparameter SAR data were shown to improve characterization of earth's surface or vegetation cover, or to generate geophysical products compare.d with optical sensors or single-channel SAR sensors alone.

SIR-C/X-SAR data over geologic targets are being used to address a broad range of topics, including volcanic terrain mapping and monitoring (Mouginis-Mark, 1995; MacKay and Mouginis-Mark, 1 996), aeolian processes (Greeley et al., 1 995; Greeley et al., 1 996), studies of climate change. (Farr and Chadwick, 1 996; Forster et al., 1 996), and lithologic and structural mapping of expose.ct (Kruse,1996) and subsurface features (e.. g. Abdelsalam and Stern, 1996; Dabbagh et al., 1996; Schaber et al., 1996). Finally, SIR-C/X-SAR data are being used for studying a broad range of oceanographic phenomena, including internal wave.s, oil slicks, fronts, eddies, and currents (Figure 2)(e.g. Stofan, et al., 1 995; Monaldo and Beal, 1995).

During the October, 1994 flight of SIR-C/X-SAR, over a million square kilometers of repeat - pass SAR interferometry data were obtained. Several orbits were designed to closely duplicate orbits from the first flight, giving a time. separation of approximately six months. Most observations during the last four days of the second flight were devoted to one-day repeat -pass data takes, over several dozen targets around the world. The Shuttle navigation was extremely accurate, and most interferometric pairs were acquired with baseline separations of no more than a few hundred meters. Formation of interferometric fringes was accomplished for all three wavelengths. Although repeat-pass interferometry is probably not the ideal method for generation of digital elevation models (DEMs), the SIR-C/X-SAR interferometry data set has produced good results for many sites (e.g. Moreira et al., 1995; Goldstein, 199S). A DEM was generated from SIR-C L-band interferometric data that extends from the California-Oregon border to the Mexican border (Figure 3). The statistical uncertainty of the DEMs heights for this traverse is typically 5-15 m rms (Rosen et al., 1995)

Repeat-pass interferometry data have also been used in studies of earth-surface change.. Zebker et a]. (1 996) used decorrelat i on measurement s among one-day repeat passes to track advancing lava flows at Kilauea volcano on the Big Island of Hawaii and to estimate rates of lava extrusion. Rosen et al. (1996) analyzed a six-month repeat-pass pair in an effort to quantify deformation of the Kilauea edifice. Rapidly advancing glaciers in the Northern Patagonian Icefield, Chile were. observe.d with one-day repeat-pass data (Rignot et al., 1996 b,c). Maps of ice motion along the radar line-of-si:,h(and maps of glacier topography were derived simultaneously.

in addition to collecting the first multifrequency and multipolarimtric data from space., thereby allowing scientists to explore. the planet in a way that has never befor e been possible, SIR-C/X-SAR represents several other engineering "firsts". In addition to selectable transmit bandwidths of 10, 20, and 40 MHz, S1 R-C also has selectable pulse lengths of 8.5, 17, or 33 μs to increase signal-to-noise ratio over low-backscatter targets. The SIR-C 1.- and C-band active phased array antennas also provide the capability to steer and shape. the antenna pattern to more optimally illuminate. the ground track, and enable operation in modes known as SCANSAR and SPOTLIGHT (Jordan et al., 199.5). For SCANSAR, the antenna pattern coverage on the ground is stepped across track during the synthetic aperture period to allow cover-agr. over a wider swath. This mode extends the swath to a width of 225 km, but at a reduced azimuth resolution of 1 00 m (Chang et a]., 1 996). For SPOTLIGHT, the boresight is positioned in azimuth to dwell on an area as the system flies by. This mode allows a higher resolution in azimuth (as good as 6 m at L-band and 3 m at C-band) for the selected area, at the expense of the along-track swath.

Future Opportunities

The Suite of spaceborne SAR systems and programs currently flying and envisioned by the international community provi de an import ant framework for addressing key science issues and applications. 1 lowever, additional interferometric and multiparameter measurement capabilities are required for long-km environmental monitoring and commercial applications (e. g. Evans et al., 1 995; Dixon, 1 995; Winokur et al., 1 995). Based on these emerging requirements, the SIR-C/X-SAR hardware will be modified by adding a 60 m boom for single-pass interferometry (Figure 4) and will be flown in the 1998-2000 timeframe to gene.rak a global topographic data base.. This mission will provide an unprecedented digital topographic map of the world equator-ward of 60-degrees latitude, which will serve as the reference data for future higher resolution topographic and topographic change studies. in a single. 11 day Shuttle flight a digital topographic map of 80% of Earth's land surface will be produced with data points spaced every 30 meters and 8 meter relative vertical accuracy. Data sufficient (o produce a rectified, terrain-corrected C-band (5.6 cm wavelength) mosaic at 30 mete.r resolution will also be acquired.

A "LightSAR" concept is also being considered which would make use of advances in materials science and hybrid structures (low mass, low lame.h volume antenna) and microelectronics (low power) to design a low cost SAR. New inflatable, deployable antenna technology is also being investigate.d to further reduce mass and size (pre-launch), and hence reduce mission costs. Low-cost X-band distributed ground terminal stations would also be validated as part of this mission. Demonstrably lower SAR mission costs will enable a variety of opportunities for scientific, operational, and commercial systems in the future.

Conclusions

SAR data provide unique information about the health of the planet and its biodiversity, as well as critical data for natural hazards and resource assessments. Interferometric measurement capabilities uniquely provided by SAR are required to generate global topographic maps, to monitor surface topographic change, and to monitor glacier ice velocity and ocean features. Multiparameter SAR data have been shown to improve land cover classifications, measurements of above-gloLuld woody plant biomass, delineation of wetland inundaticm, and measurements of snow and soil moisture over optical sensors or single-channel SAR sensors alone. Although the suite! of space.borne SAR systems currently flying, and envisioned by the international community provide an important framework for addressing key science issues and applications, additional interferometric and multiparameter measurement capabilities are required for long-term environmental monitoring anti commercial applications

Figure Captions

Figure 1. Shuttle hand-held photo taken by astronaut crewmember (M) and coincident SIR-C image of volcanic eruption of Kliuchevskoi volcano on the Kamchatka peninsula which began September 30, 1994. The image shows an area approximately 30 kilometers by 60 kilometers that is centered at 56.18 degrees north latitude and 160.78 degrees east longitude. North is toward the top of the. image. Red=L-band, horizontally transmitted and received (LHH); green= L-band, horizontally transmitted and vertically received (LHV); blue=C-band, horizontally transmitted and vertically received (CHV).

Figure 2. SIR-C image of an offshore. drilling field about 150 km west of Bombay, India showing oil slicks (dark streaks), internal waves (upper center), and ocean swell (blue areas adjacent to internal waves). Red=L-band, vertically transmitted, vertically received (LVV) polarization, green=average of L-band (VV) and C-band (VV), and blue= C-band (VV).

Figure 3. DEM generated from SIR-C L-band interferometric data extending from the California-Oregon border to the Mexican border. The statistical uncertainty of the. heights for this traverse is typically 5-15 m rms (Rosen et al., 1995).

Figure 4. Artist's conception of SIR-C/X-SAR hardware modified by adding a 60 m boom for single-pass interferometry.

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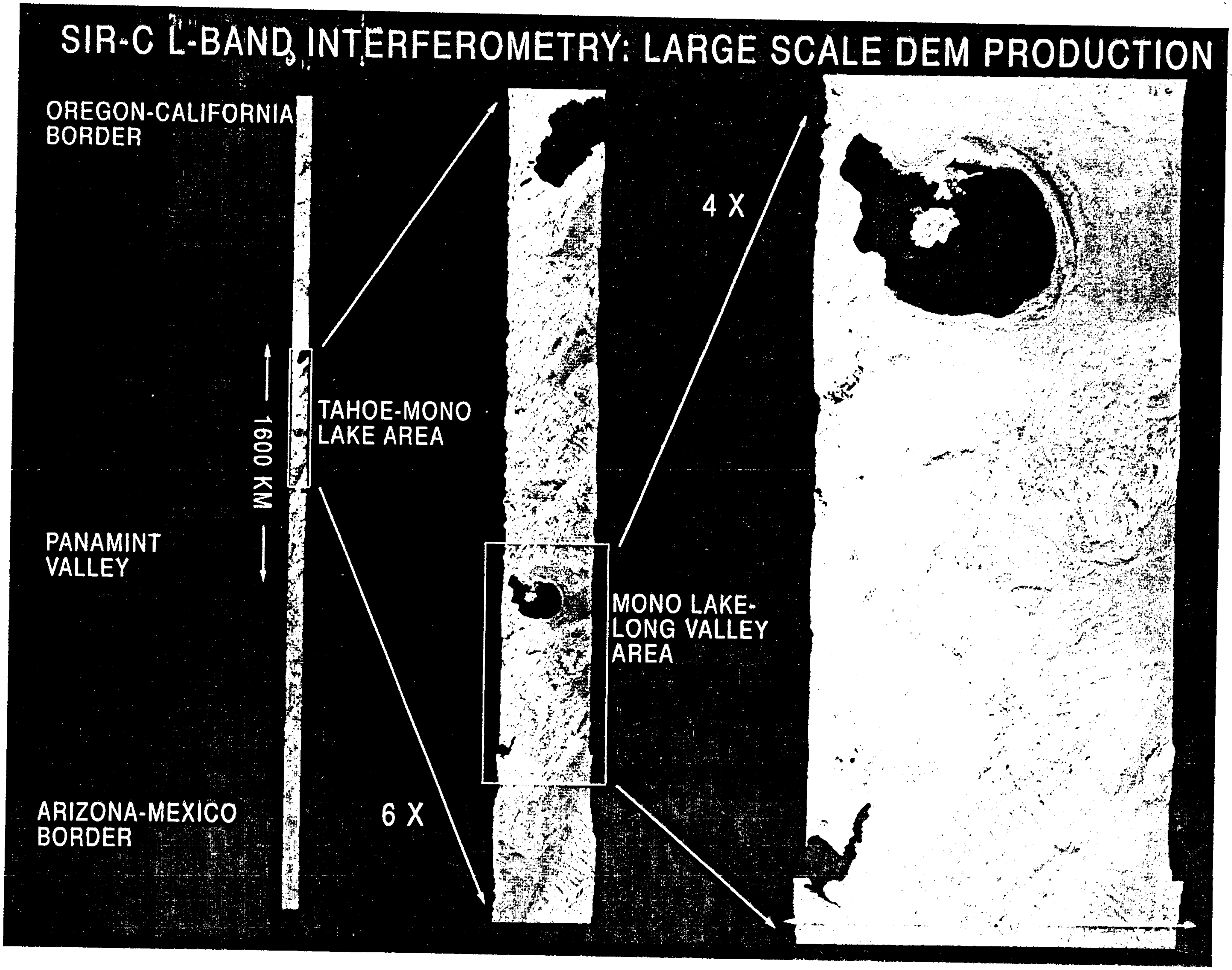
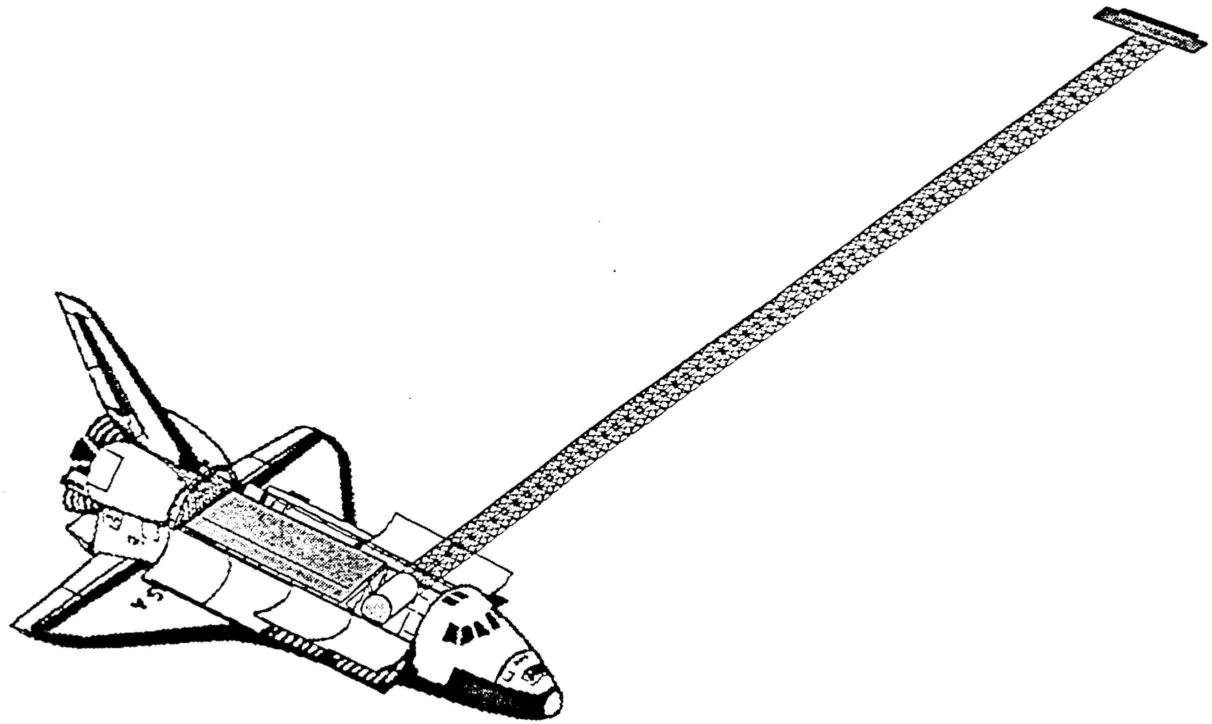
Additional information about imaging rack, sample data sets and software to display them arc. available on the World Wick Web, at URL:

http://southport.jpl.nasa.gov . APPROVED FOR EXTERNAL RELEASE ON WWW (CL 96-0955)

Evans, Figure 1

Evans, Figure 2


SIR-C L-BAND INTERFEROMETRY: LARGE SCALE DEM PRODUCTION
OREGON-CALIFORNIA BORDER
PANAMINT VALLEY
ARIZONA-MEXICO BORDER
1600 KM
TAHOE-MONO LAKE AREA
6 X
MONO LAKE-LONG VALLEY AREA
4 X



Evans, Figure 4